Abstract

In this doctoral thesis, we investigate the effects of the experimental bounds (derived from the precision measurements of processes involving the Standard Model fields) and the theoretical constraints (arising from the consistency requirements of the considered model) on the prospects for indirect searches for physics beyond the Standard Model (BSM). This program can be realized within two distinct but complementary methods: the bottom-up and top-down approaches. The bottom-up approach focuses on studying discrepancies between experimental results and the Standard Model (SM) predictions without assuming the form of the underlying theory. With the lack of direct discoveries of new particles in our accelerator experiments and with the Large Hadron Collider (LHC) reaching its energy limit, this approach is becoming increasingly common for uncovering physics BSM. Conversely, the top-down approach is based on the specific Standard Model extensions proposed to address one or more of its shortcomings. In this work, we present three distinct, but complementary examples of studies based on these two approaches, providing a broader perspective on some current areas of interest in the field of particle physics. We first present two project that follow the bottom-up approach to searches for BSM physics. The first project, "`SmeftFR` v3 – Feynman rules generator for the Standard Model Effective Field Theory", resulted in a numerical tool designed for calculations in the Standard Model Effective Field Theory (SMEFT). The SMEFT allows the parametrization of BSM physics by higher-dimensional operators constructed from the SM fields, enabling the study of BSM phenomena in a model-independent way. Although very useful, the SMEFT is also a highly complicated framework, and tools like this one prove indispensable for efficient calculations. The second study, "Double Higgs boson production via vector-boson fusion (VBF) in SMEFT next-to-leading order (NLO) in the EFT expansion", provides a detailed calculation (with the use of the `SmeftFR` v3 package described in the previous chapter) of a specific process including effects of dimension-6 and dimension-8 bosonic operators. As a result, we obtain estimates of the maximal potential enhancement of this process within the SMEFT framework for the High Luminosity LHC (HL-LHC) accelerator experiment. The third and final study, "Vector-like fermions, real scalar and Higgs boson phenomenology", is a representative example of a top-down approach to new physics searches. Assuming specific BSM particle content — vector-like fermions (VLF) and a real scalar singlet — we work out theoretical constraints on the model parameters and calculate the possible impact of these BSM particles on the process of double Higgs boson production via gluon fusion, on electroweak precision observables, the electroweak phase transition and gauge couplings unification. Additionally, we presented a procedure of matching between the SMEFT and the considered VLF and scalar extensions, providing a bridge between the two approaches. While all three of these research projects serve as representative examples of high-standard research projects, their combination highlights and emphasizes indirect searches for BSM physics as a promising approach to new physics searches.